Reliability evaluation of Fatigue crack signal in austenite stainless steels

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Abstract：This paper investigates the influence of machining process on eddy current signals of fatigue cracks in low carbon austenite stainless steels. Several fatigue cracks are created using four point bending method. The grinding process on crack mouth after the formation of fatigue crack seals the crack and gives certain amount of conductivity. This phenomenon on fatigue cracks is confirmed through comparison with the numerical simulation of ECT signals.

Keywords: ECT, Fatigue crack, grinding, electrical contact.

1. Introduction

The austenitic steels most commonly used in hydrocarbon processing plant are AISI types 304, 304L, 321, 316, 316L. In the nuclear industries, control rod components, pipelines are manufactured from AISI types 316, 304, and 321 stainless steels. The upper sections of the boiler are type 316 stainless steels. So a lot of the applications of stainless steels involve high temperature and/or corrosive environment [1, 2]. So that fatigue crack formation under the influence of environment is a major concern for the integrity of component, putting forward the question on how we accurately inspect crack existence in austenite stainless steels.

Austenite stainless steels have relatively low carbon content. The yield strength of austenite stainless steels is relatively low, usually being 150–300 MPa in the annealed state, and the ductility is relatively high [1, 3]. In the maintenance of vessel or pipeline made of stainless steel, we often need to make preparation for welding process during repairing of damages. The surface grinding and polishing to remove oxidation layer or contaminant will create great deformation in the surface. To what extent this deformation will affect damages and give confusion about the appearance of the damage is very important, especially when we inspect surface using electromagnetic testing method like ECT which has the skin depth effect to examine metal materials.

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The purpose of this paper is to evaluate the influence of grinding process on inspection of fatigue crack using eddy current testing and then using numerical simulation to verify the above effect which is caused by electrical contact of the crack mouth.

2. Specimen and experimental procedures

2.1 Specimen material and fabrication

The material of specimen used in this experiment is AISI316L austenite stainless steels. The chemical composition of the material is listed in Table 1. The carbon content is very low, about 0.024 weight percent, to make sure that the specimen has high ductility.

Table 1 Chemical composition of specimen (wt%)

C	Si	Mn	P	S
0.024	0.56	1.03	0.022	0.001
Cu	Ni	Cr	Mo	N
0.26	10.56	16.19	2.07	0.0566

The profile of specimen used in this experiment is shown in Fig.1. There is an upper convex section with a height 10 millimeters. A triangular notch with 60° is fabricated using EDM with a height of 5 millimeters as a concentration locus to introduce fatigue cracks under bending moment. The fatigue cracks are introduced using the four-point bending method at room temperature.

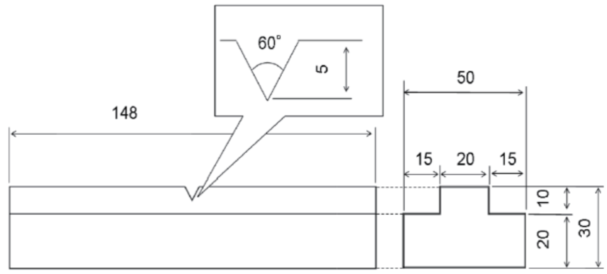

Fig.1 Specimen profile

After fatigue cracks are introduced, the upper convex sections are removed using milling cutter to the level same as the low wider section, and then using a pancake probe scans fatigue cracks and the ECT signals are obtained.

2.2 Evaluation method and sequence

After the grinding process for removing the upper convex section on the specimen, the fatigue crack is evaluated by a pancake ECT probe for the first time. After obtaining crack depths using destructive testing, numerical simulation is conducted to simulate the fatigue crack signals. Through comparison between numerical simulation and experiment results, the abnormity of ECT signals is manifested. After that external stress is applied to the fatigue cracks which have undergone grinding process by milling cutter, and then the second evaluation of fatigue crack using the same ECT probe is conducted. And comparing the two evaluation results of ECT signals to get the idea about the effect of grinding process on the ECT signals. In the last, numerical simulation is conducted to verity the effect of electrical contact of crack mouth caused by the grinding process. The numerical simulation method is based on reduced *A*, edged finite element method [4]. The number of elements are 13608.

3. Results and discussion

Three fatigue cracks are formed using four-point bending method, then removing the upper convex section and getting the ECT signals. In order to get the depth of fatigue cracks, the fractography in the midway of the length direction is obtained after destruction. The parameters about three cracks are listed in Table 2.

Numerical simulation is conducted to get the supposed ECT signals of these three fatigue cracks with a rectangular EDM slit with length 12mm, width 0.04mm and depth the same as that got from fractography. Comparison between the results from the simulation and experiment for the three fatigue cracks is shown in Fig.2, and a big discrepancy in amplitude and phase among simulation and experiment are observed.

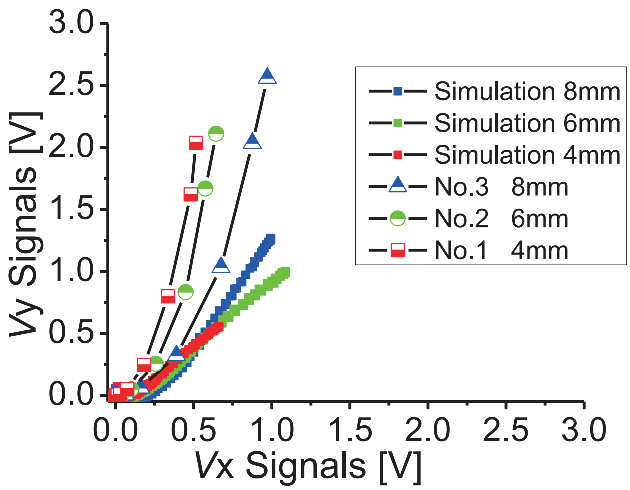

Fig.2 Comparison between simulation and experiment result

From the above result, a certain amount of conductivity is possibly created through deformation of the surface caused by milling cutter. In order to confirm this phenomenon, when the upper convex section is removed, a small number of additional stress cycles about 1000 are applied to No.1 specimen which is created under 265,000 stress cycles in order to separate the contact region in the mouth of the crack, and the fatigue crack is scanned using ECT for the second time. The signals before and after the stress cycle are shown in the Fig.3 together with simulation result with depth 4mm in Fig.2. From this result, additional cycles change the ECT signals toward the direction of simulation with EDM slit, that is to say the effect of grinding is removed by the additional cycles. The fractography of No.1 crack is got after EDM machining and polishing with sandpaper which is shown in Fig.4. From this picture, the section near the crack mouth is slightly invisible, so a certain portion of the crack mouth which is sealed by the grinding process and then gives a certain amount of conductivity around crack mouth region.

Table.2 The parameter of fatigue cracks

Specimen ID	Load (kN)	Stress cycles	Stress ratio	Amplitude of ECT signals (V)	Depth evaluated by destructive testing (mm)
No.1	30	265000	0.1	0.87	4.0
No.2	30	350000	0.1	1.47	6.0
No.3	30	420000	0.1	1.61	8.0

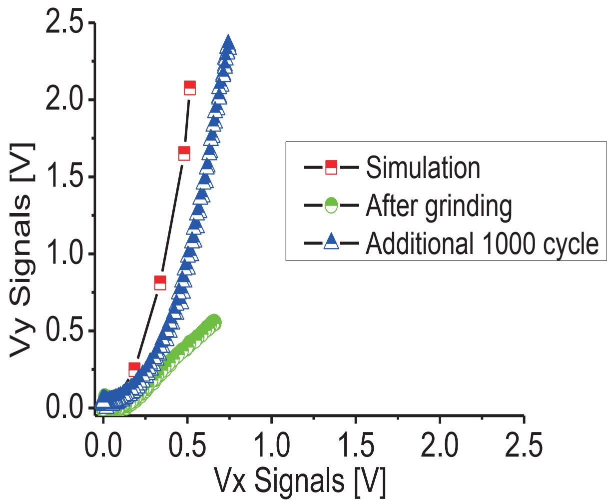

Fig.3 Signal change after additional stress cycles

Fig. 4 Fractography of crack of stress cycle 265,000

The conductivity in the crack mouth caused by the grinding process is confirmed by numerical simulation of the EDM slit. The model used in the simulation is shown in Fig.5. In the upper section near the crack mouth, the same amount of conductivity with bulk material about 1.35×10^6 S/m is given, by changing height of the region with conductivity to examine how the signal changes. The simulation results of No.1 specimen using EDM slit with length 12mm, width 0.04mm and depth 4mm are shown in Fig.6. Once the conductivity is given in the crack mouth, the simulation signal rapidly decreases toward experimental result. The same simulation is also conducted for No.2 and No.3 specimen. The same phenomenon in Fig.6 is also shown in those two simulation results. So the conductivity is confirmed by the above simulation result.

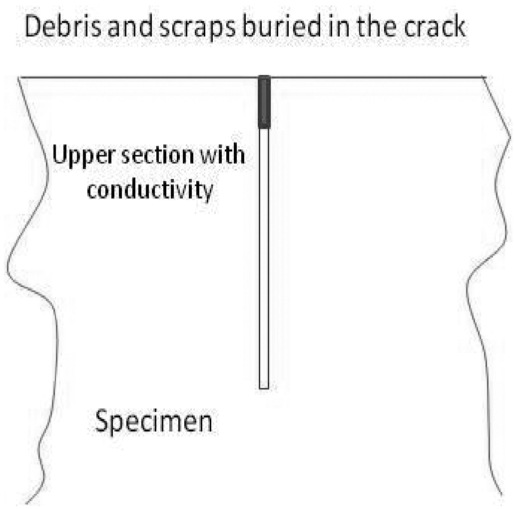

Fig.5 Model used in the simulation

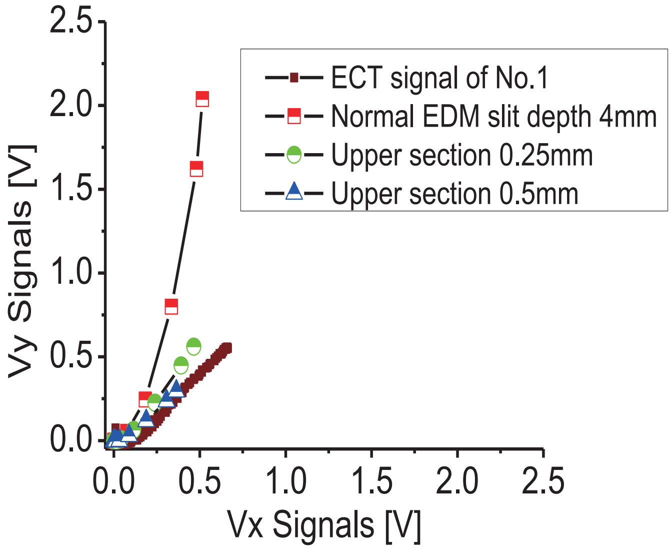

Fig.6 Simulation result of No.1 specimen

4. Summary

The grinding process on low carbon austenite stainless steel will create a certain depth of plastic deformation in the surface. This grinding process will deform the crack mouth and create electrical contact, then gives a certain amount of conductivity in the crack mouth. This electrical contact of the crack mouth will reduce the amplitude of the ECT signal and shift its phase angle. If the fatigue crack is located in the facet of the component needed to be fabricating for welding or other processes. The influence of surface treatment must be considered when evaluating the crack using eddy current testing.

5. Acknowledgement

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References

[1]Marshall, P. (1984). Austenite stainless steels: Microstructure and mechanical properties, Springer Science & Business Media, pp. 408-417.

[2]Wood, D. S. (1982). Mechanical properties data needs in type 316 steel for fast reactor application, Int. Conf. Mech. Behavior and Nuclear Applications of Stainless Steel at Elevated Temperatures, Varese, London, Metals Society, pp. 238-242.

[3]Yan, F. K. (2012). Strength and ductility of 316L austenite stainless steel strengthened by nano-scale twin bundles. Acta Materialia 60 (2012) 1059–1071.

[4]Hiroyuki Fukutomi, Haoyu Huang. (1998). Identification of crack depths from Eddy current testing signal. IEEE Trans. Magn, 34, No.5, pp. 2893-2896.